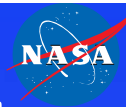


National Aeronautics and Space Administration

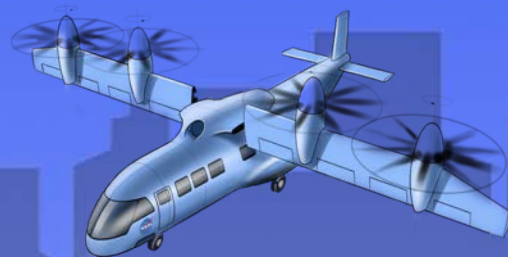


Electric Motor Noise from Small Quadcopters

Part I – Acoustic Measurements



AIAA/CEAS Aeroacoustics Conference
June 25-29, 2018
Atlanta, Georgia

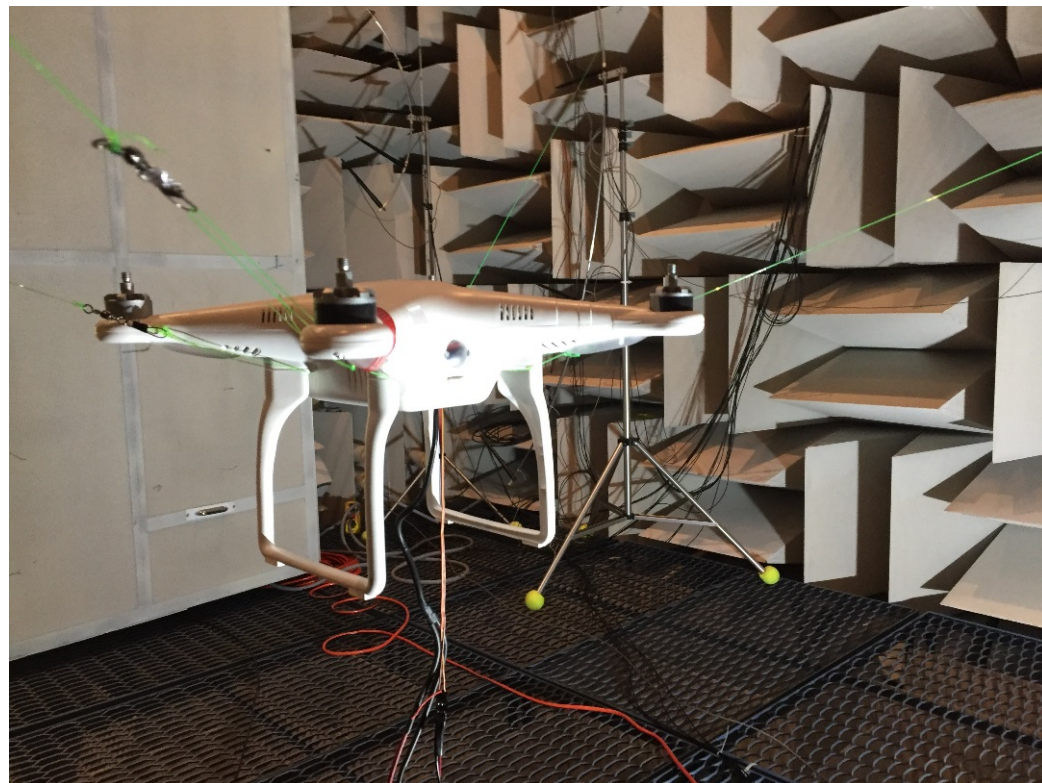


Dennis L. Huff
Brenda S. Henderson
NASA Glenn Research Center



Motivation

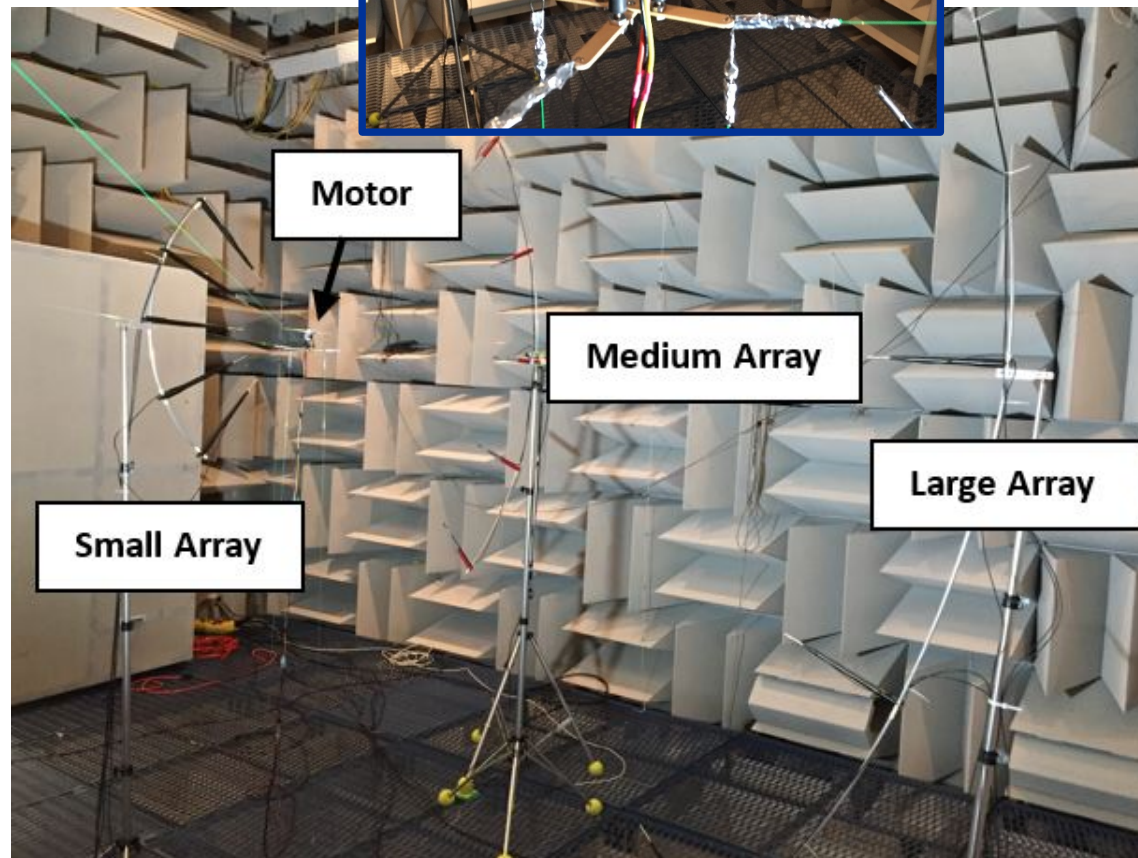
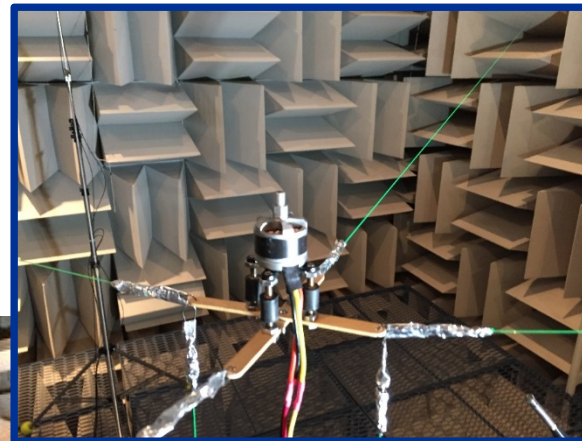
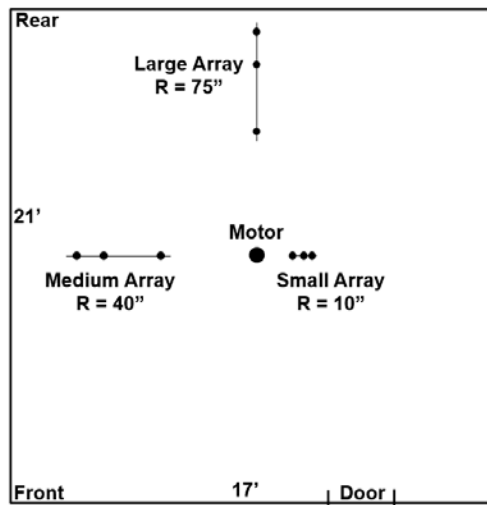
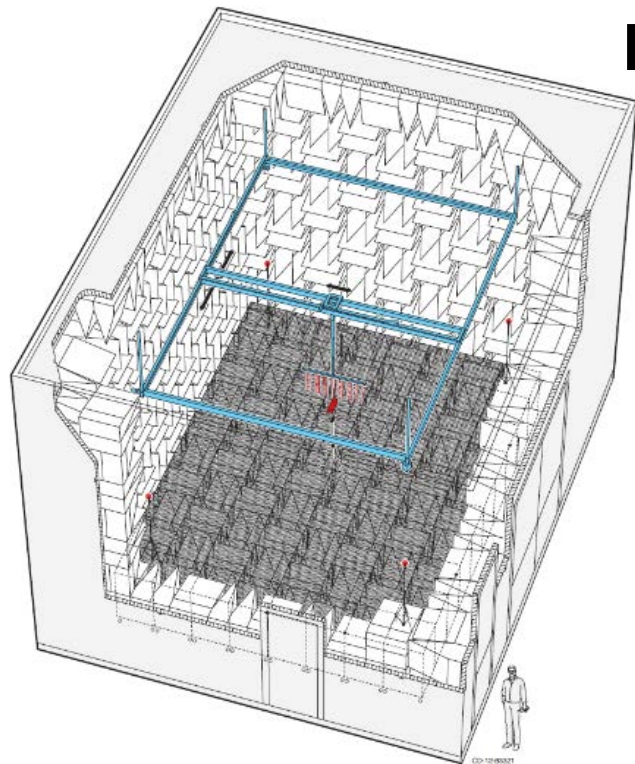
- **Electric motors driving small Unmanned Aircraft Systems (sUAS) propulsors.**
- **Noise expected to be problem, especially for Urban Air Mobility (UAM) missions.**
- **Noise sources need to be understood (propeller, motor, etc.).**
- **Need noise prediction methods for electric motors.**



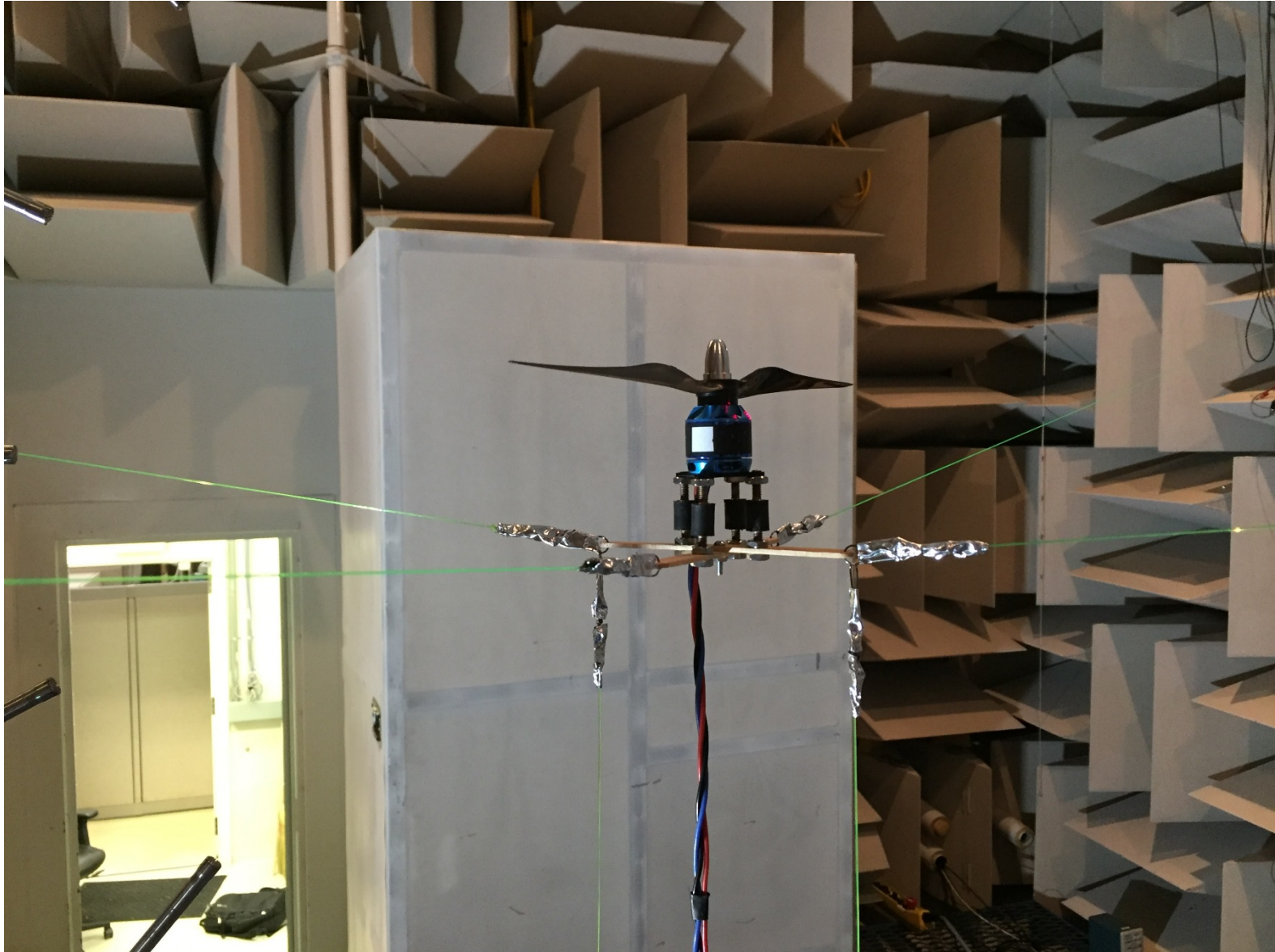
Companion paper in this session will present source characteristics.

Future work will focus on larger motors.

Experimental Setup



Motor & Propeller With Tether



Motor Only With Tether





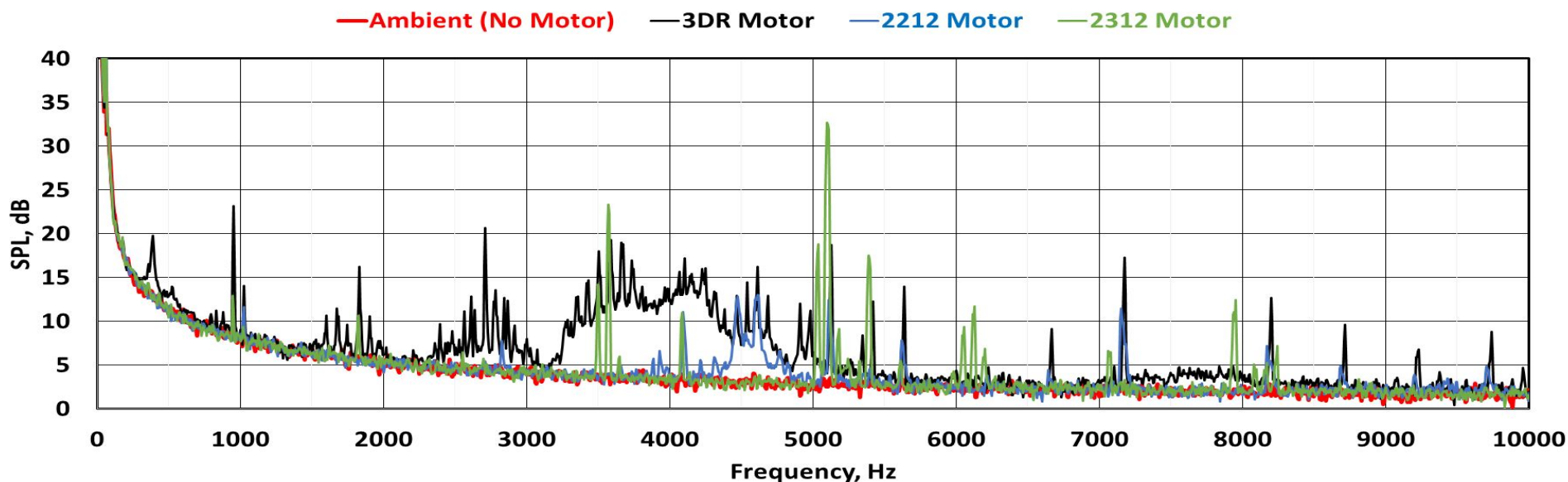
Test Matrix

	3DR “Blue”	2212	2312
Speed Variation (RPM)	4380, 5370, 6260	4380, 5370, 6260, 4773	4380, 5370, 6260, 4773
Acoustics (Small, Medium, Large Arrays)	X	X	X
Speed Controllers			
E300	X	X	X
3DR	X	X	-
420S	-	X	X
Load			
Motor Only	X	X	X
2-Bladed	X	X	X
3-Bladed	-	-	X
Phased Array	X (location study)	X	X
Current Probe	2 loops	1 loop	1 loop
Ping Test	X	X	X
Motor kV Constant (RPM/Volt)	850	920	960





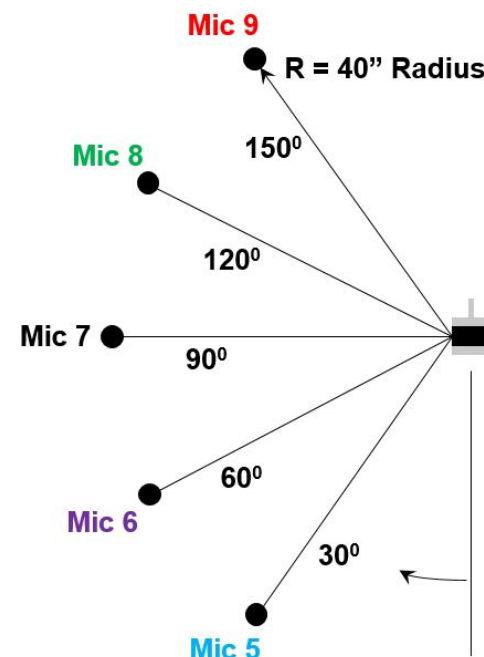
Background Noise



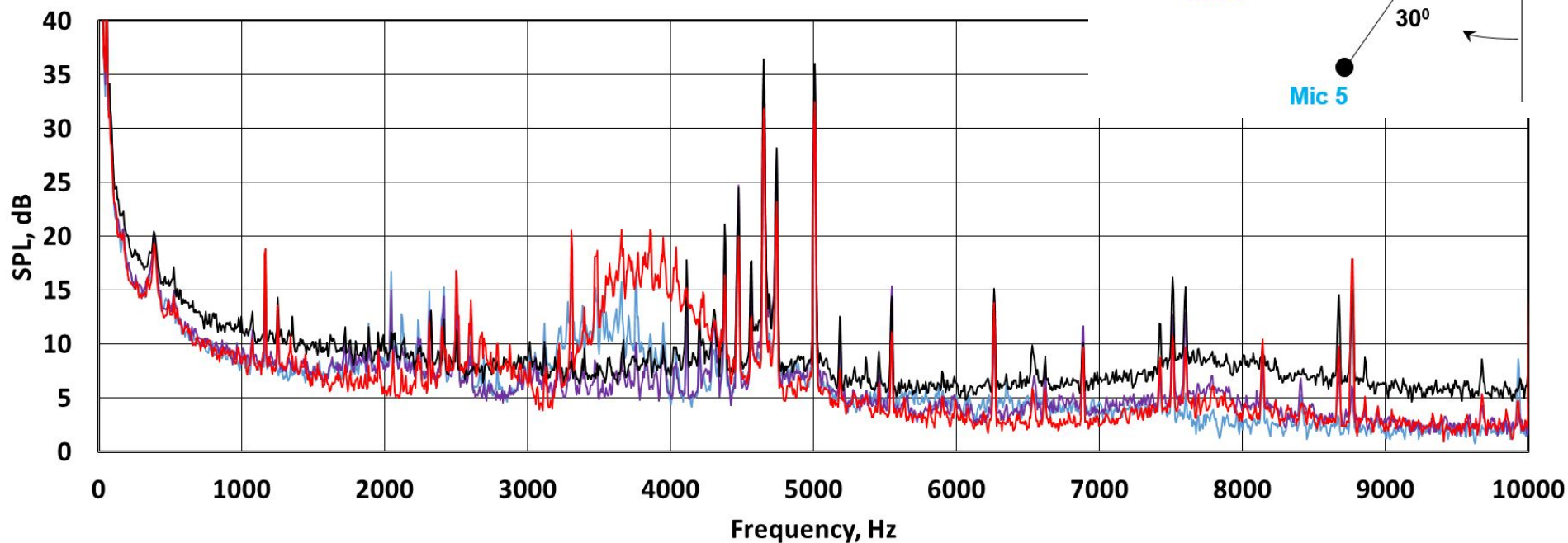
- **Motor-only SPL comparisons for three motors, microphone 9 on medium array, 4380 RPM.**
- **Noise floor from 1/4-inch microphones, not chamber**



3DR Motor Spectra, 5370 RPM

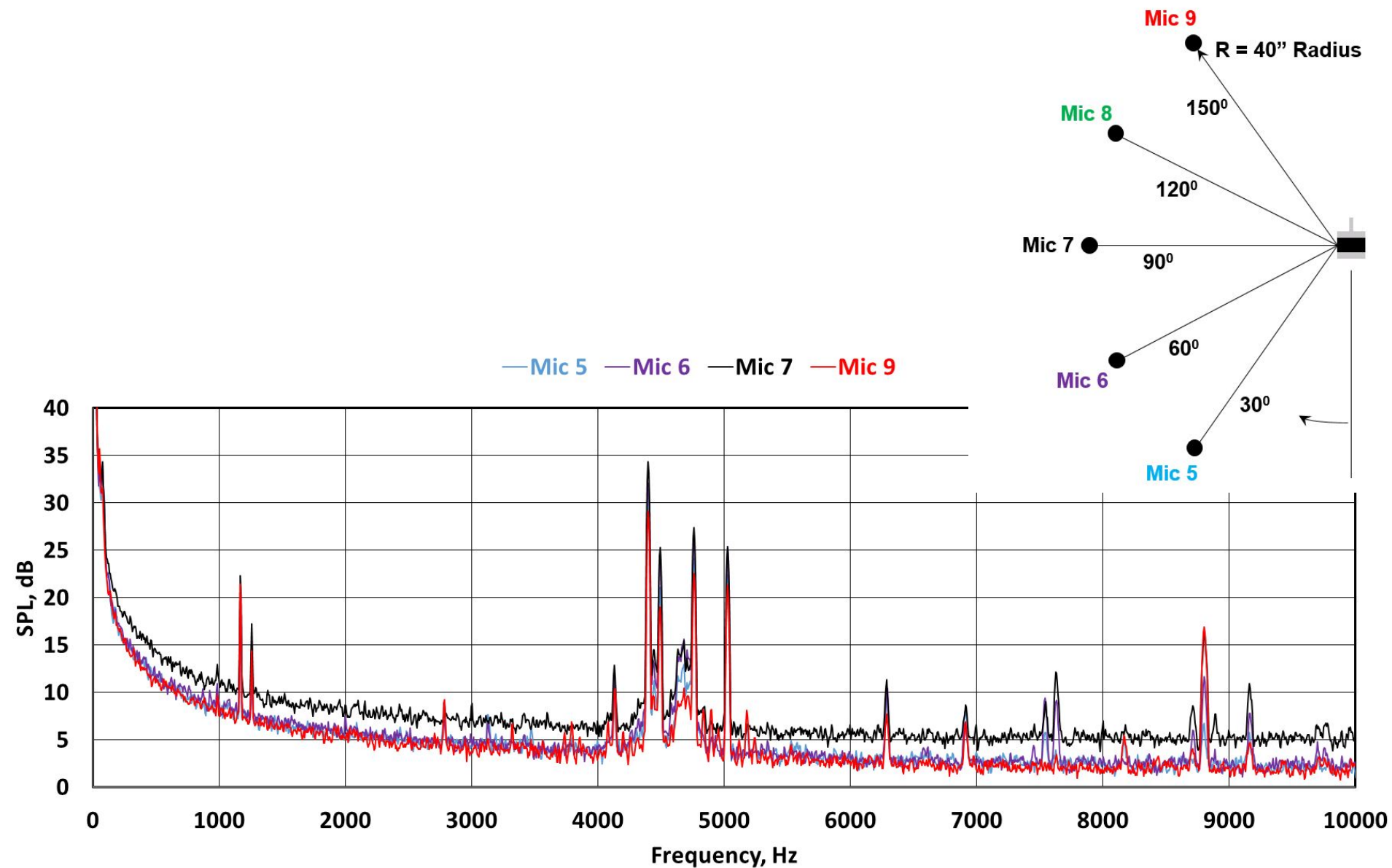


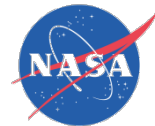
— Mic 5 — Mic 6 — Mic 7 — Mic 9



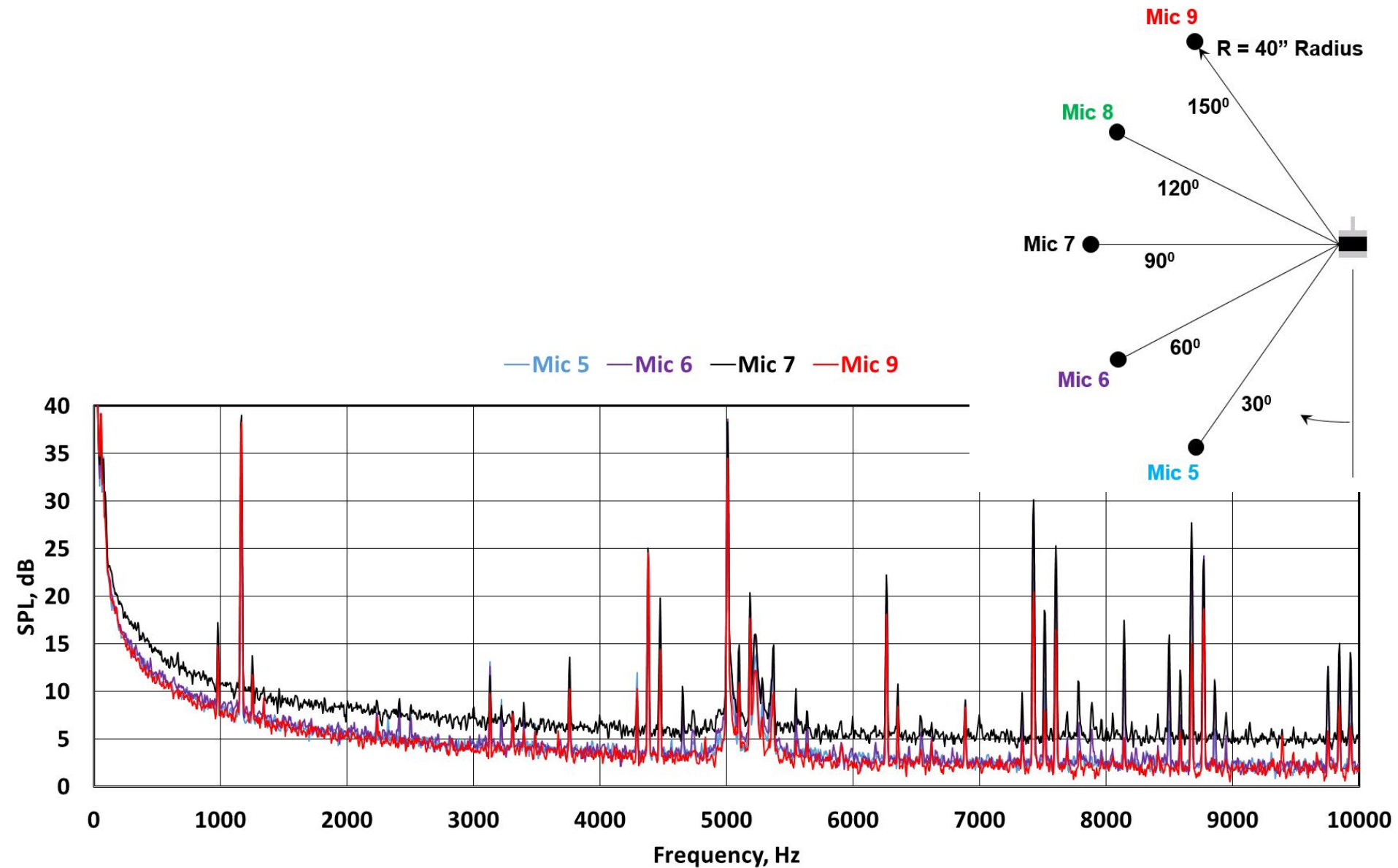


2212 Motor Spectra, 5370 RPM



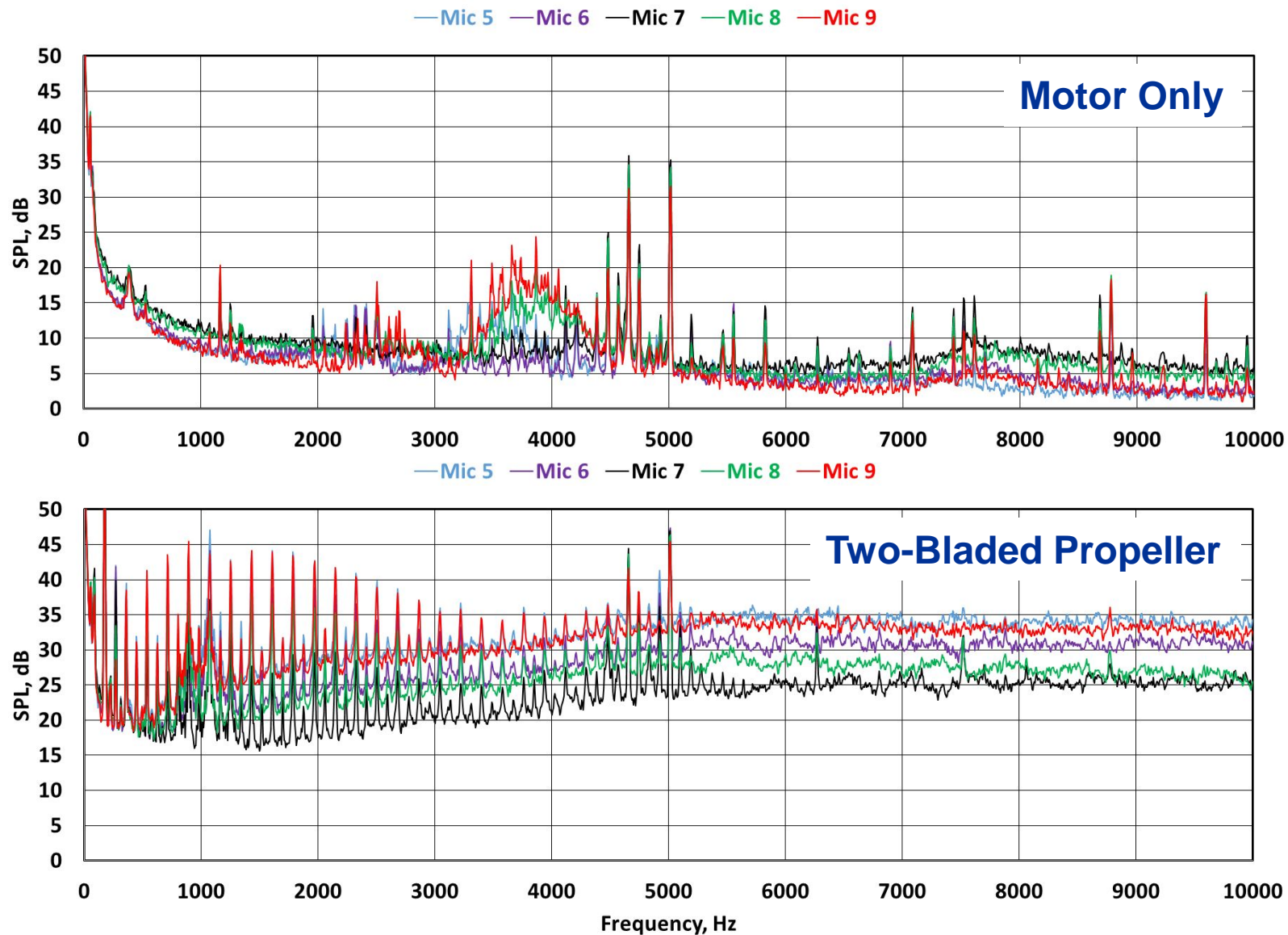


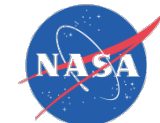
2312 Motor Spectra, 5370 RPM





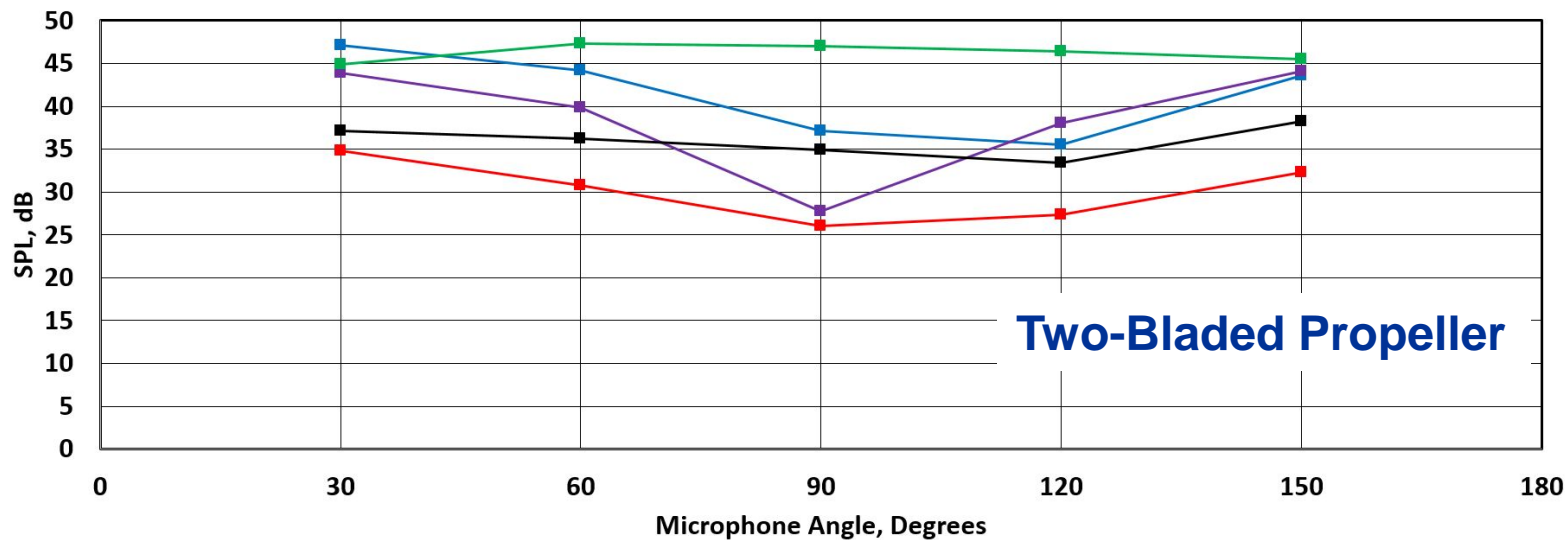
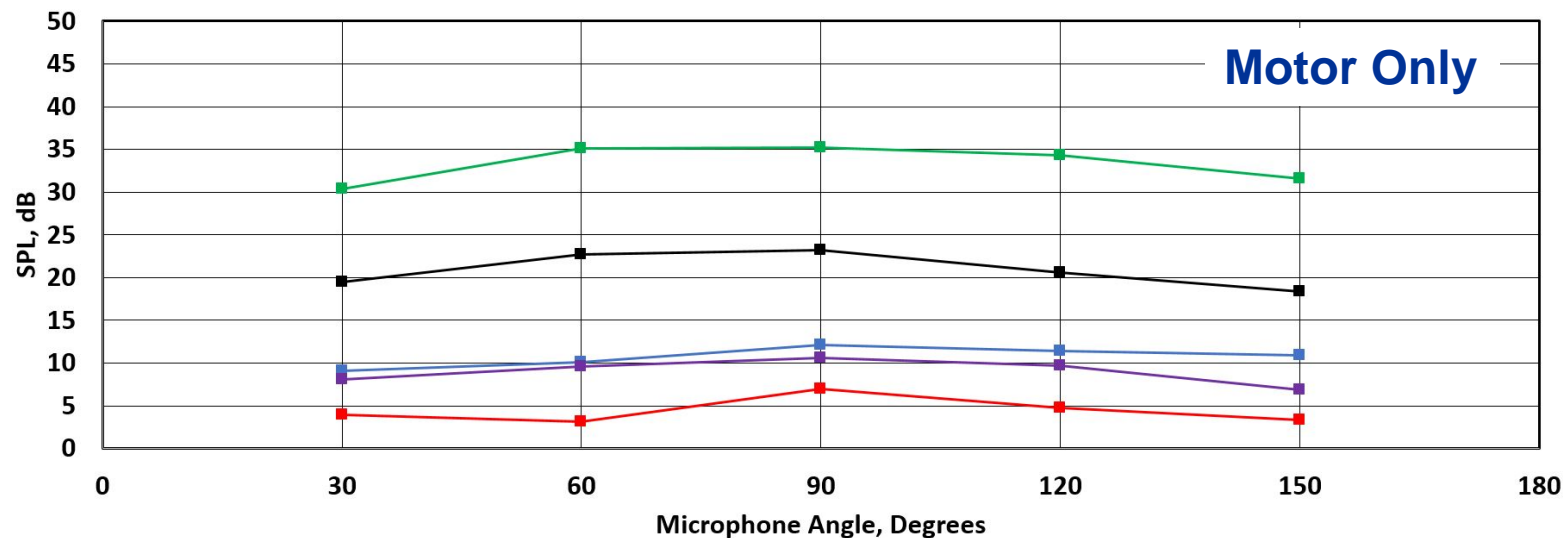
3DR Motor Only vs With Propeller, 5370 RPM





SPL Directivity, 5370 RPM

—■— 1074 Hz —■— 1434 Hz —■— 4749 Hz —■— 5017 Hz —■— 6995 Hz

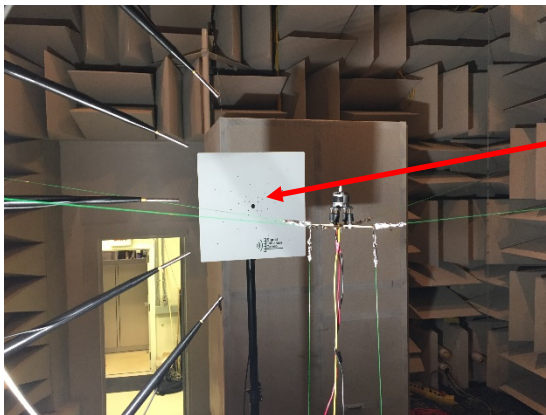
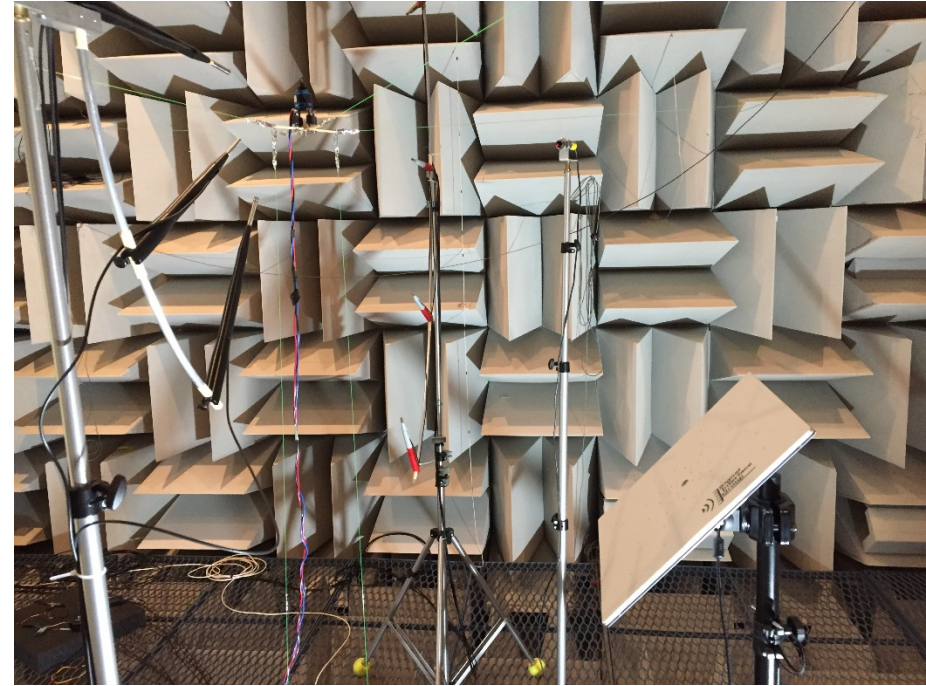


Phased Microphone Array

Normal to Motor

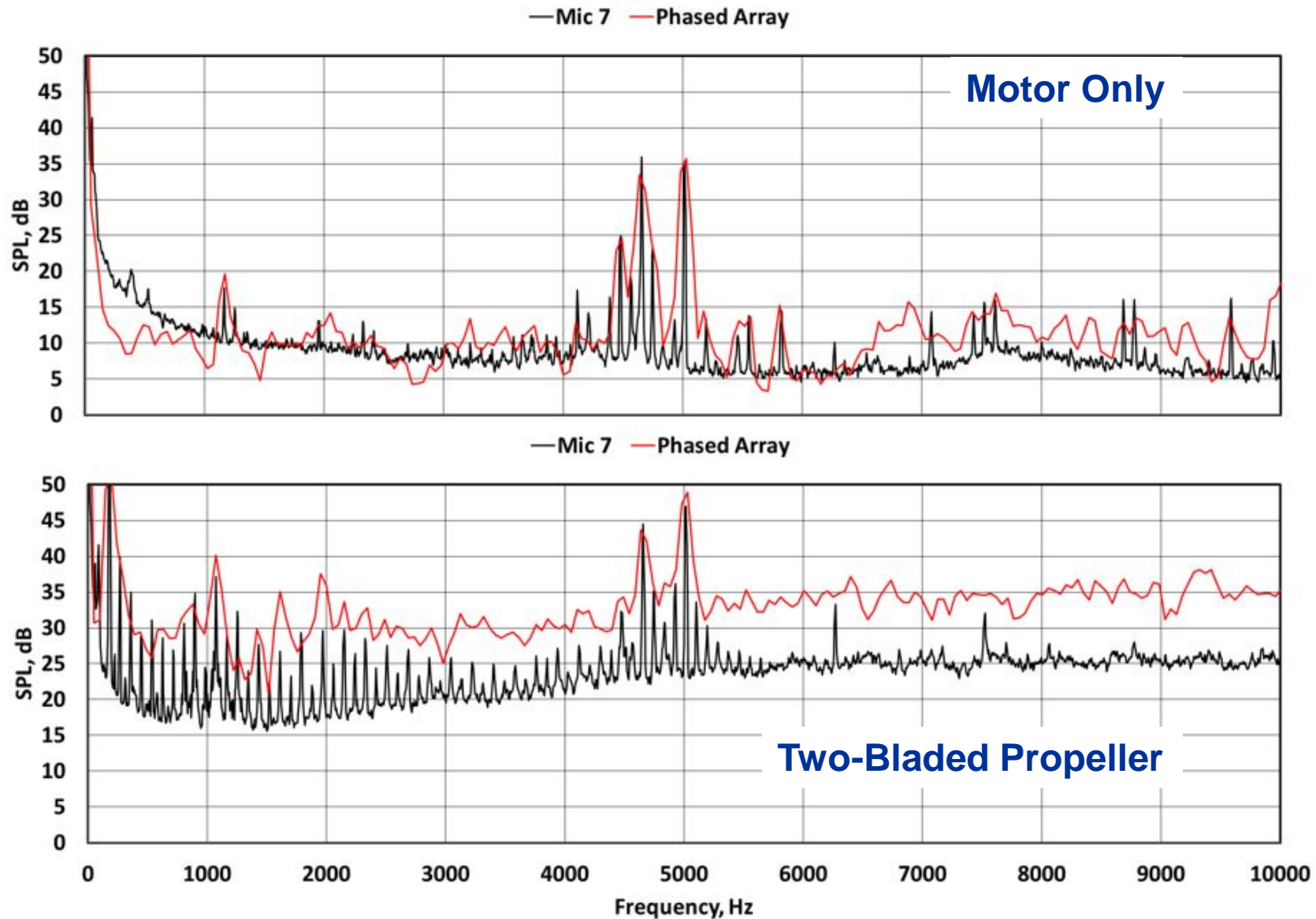


Below Motor

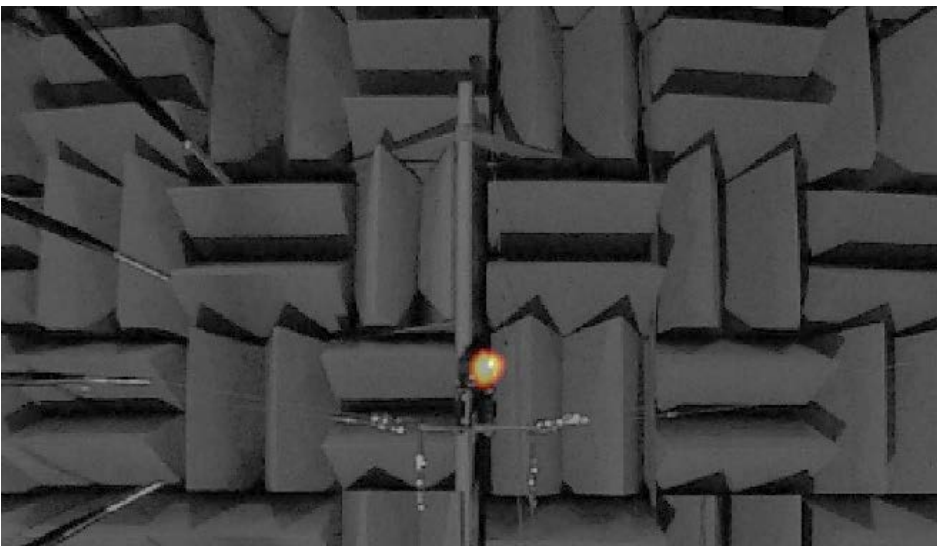


Microphone 2 used for phased array acoustic spectra is located toward the center

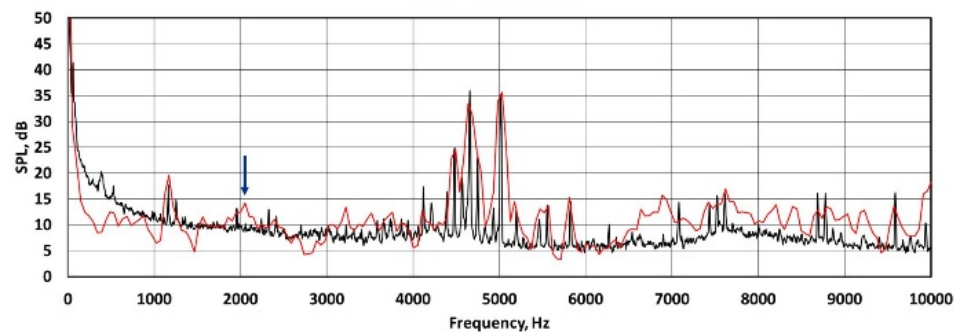
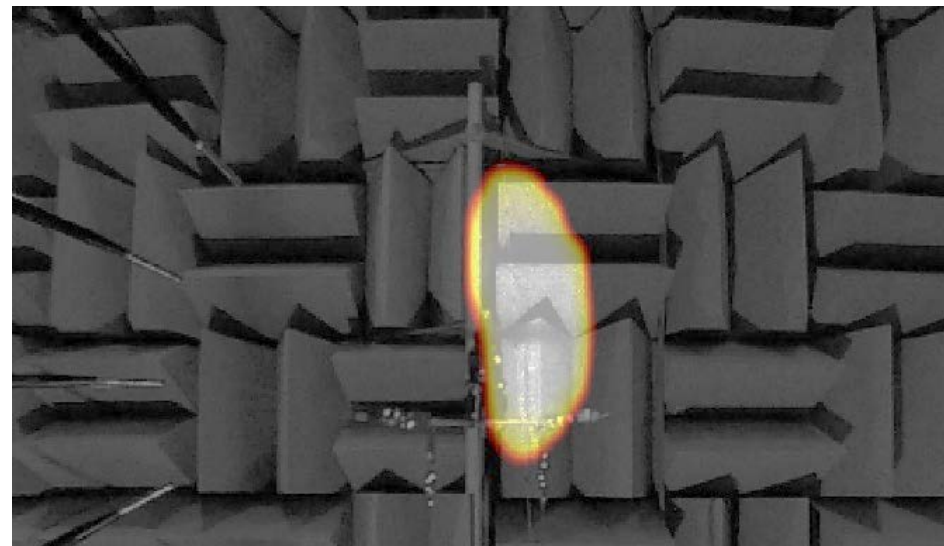
3DR Motor Only vs With Propeller, 5370 RPM



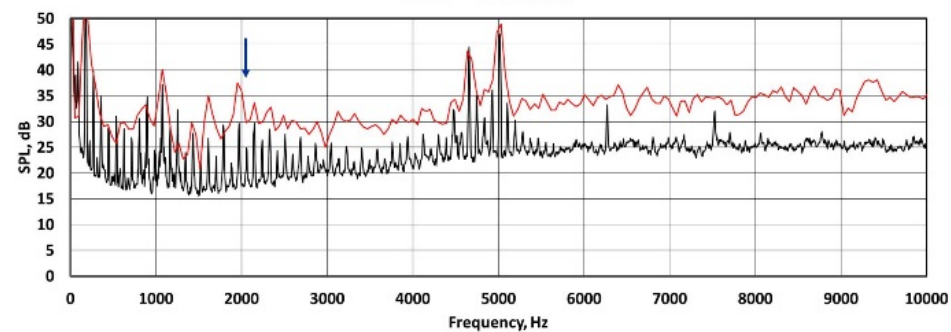
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 2050 Hz



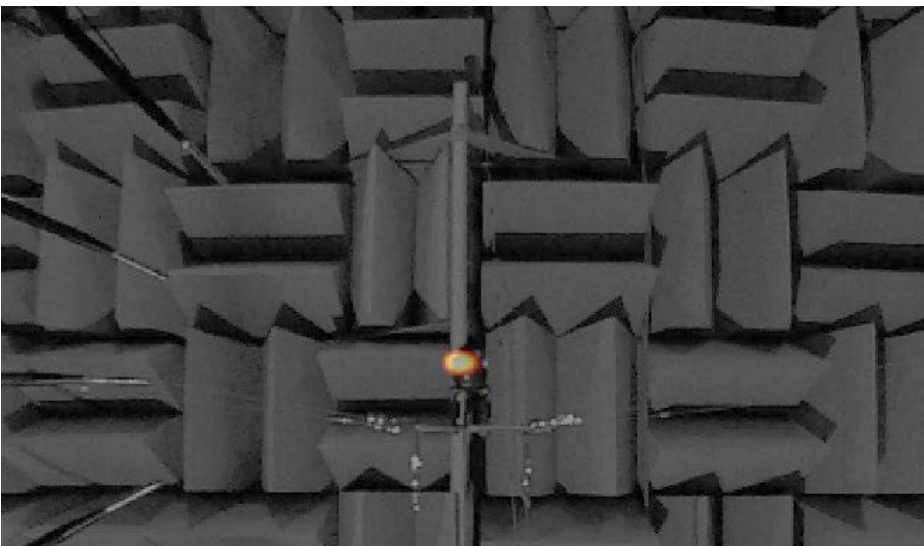
— Mic 7 — Phased Array

**Motor Only**

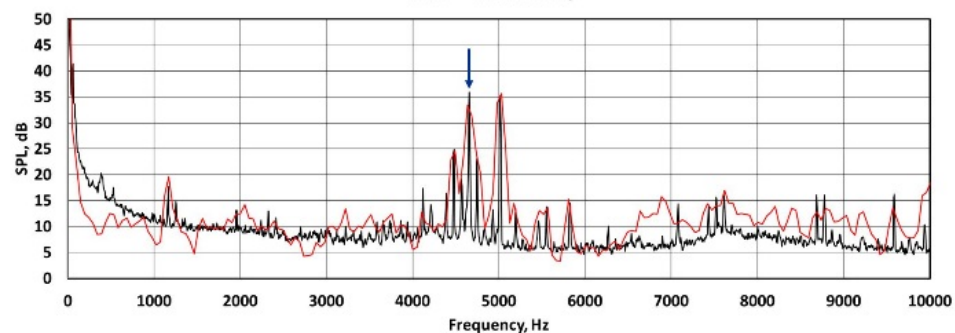
— Mic 7 — Phased Array

**Two-Bladed Propeller**

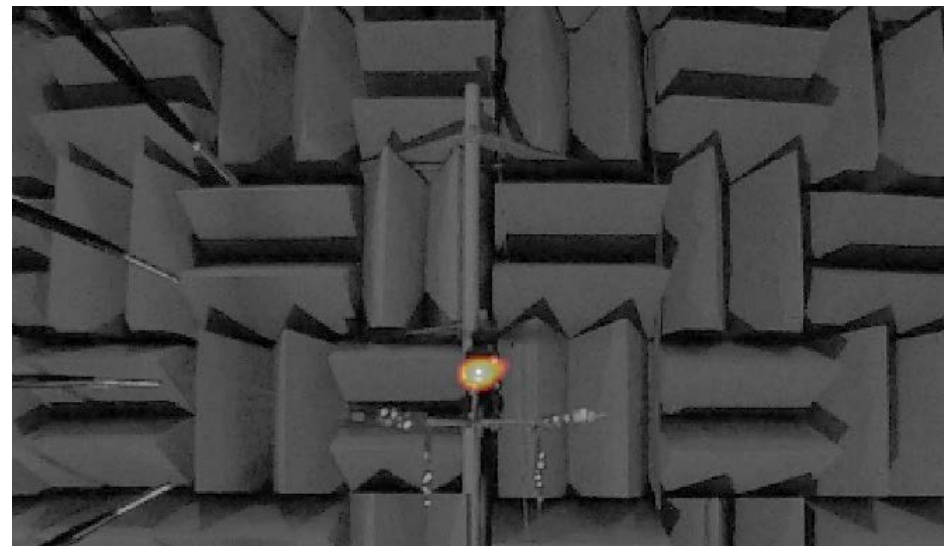
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 4638 Hz



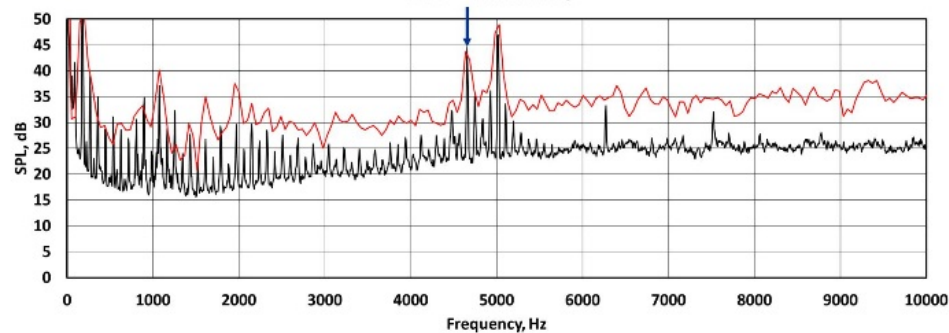
— Mic 7 — Phased Array



Motor Only

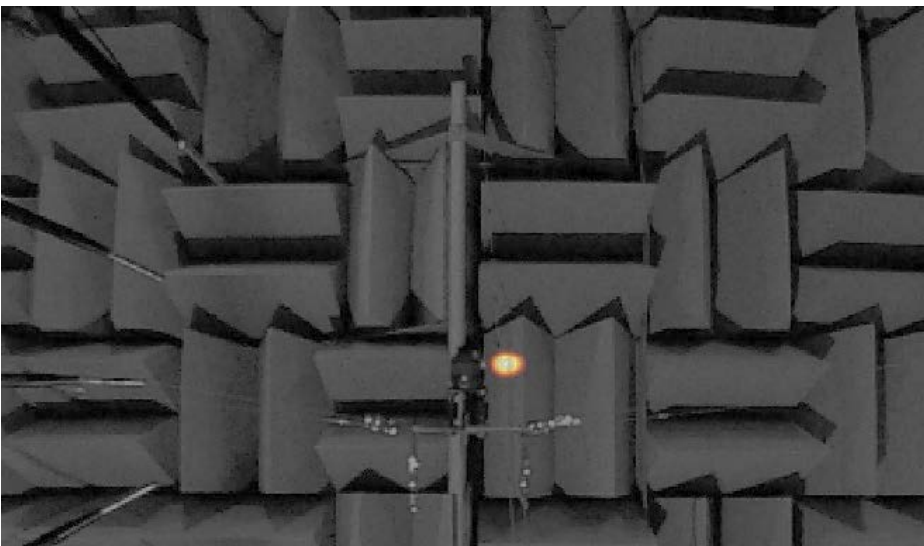


— Mic 7 — Phased Array

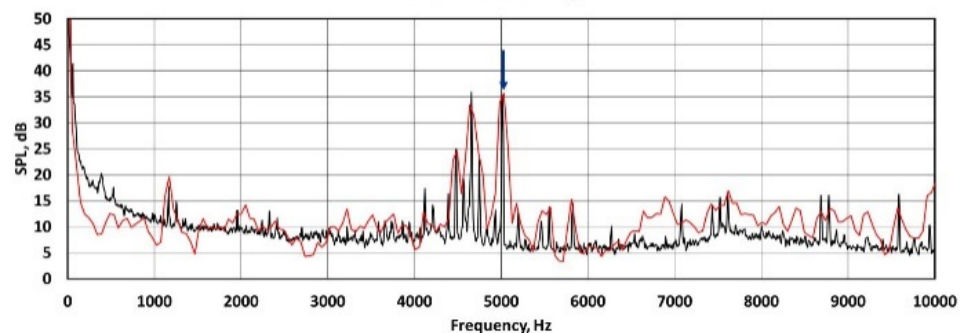


Two-Bladed Propeller

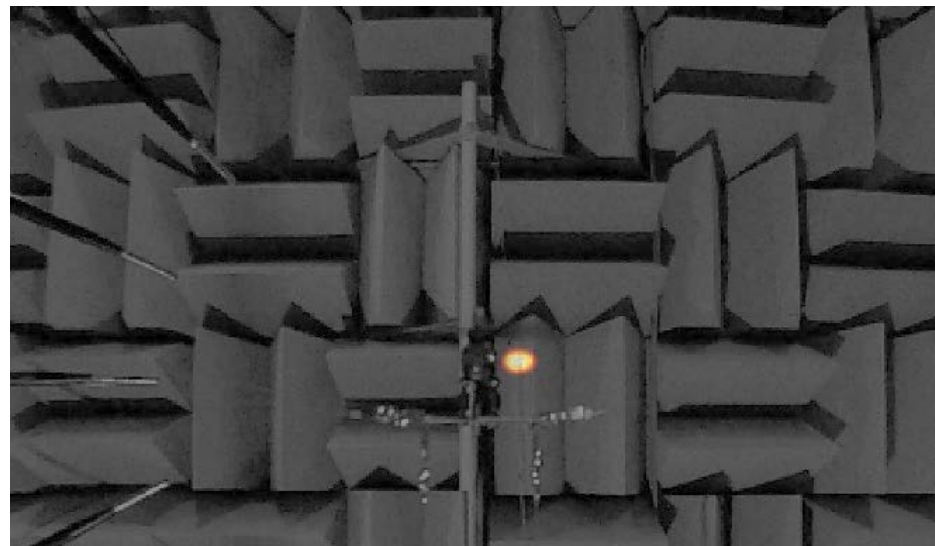
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 5029 Hz



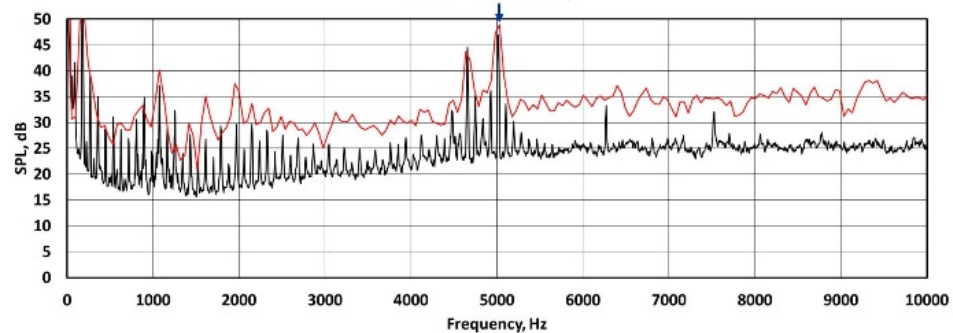
— Mic 7 — Phased Array



Motor Only

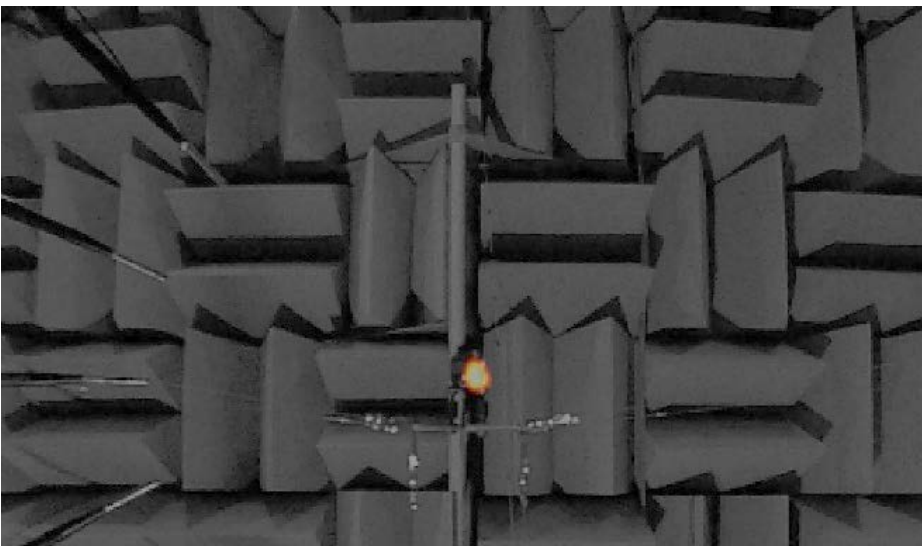


— Mic 7 — Phased Array

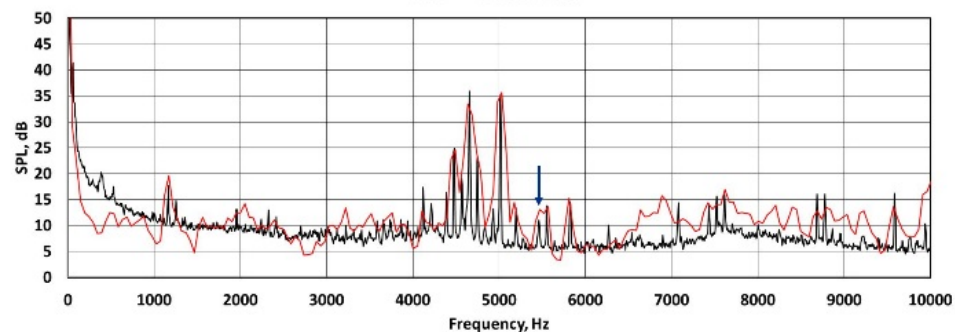


Two-Bladed Propeller

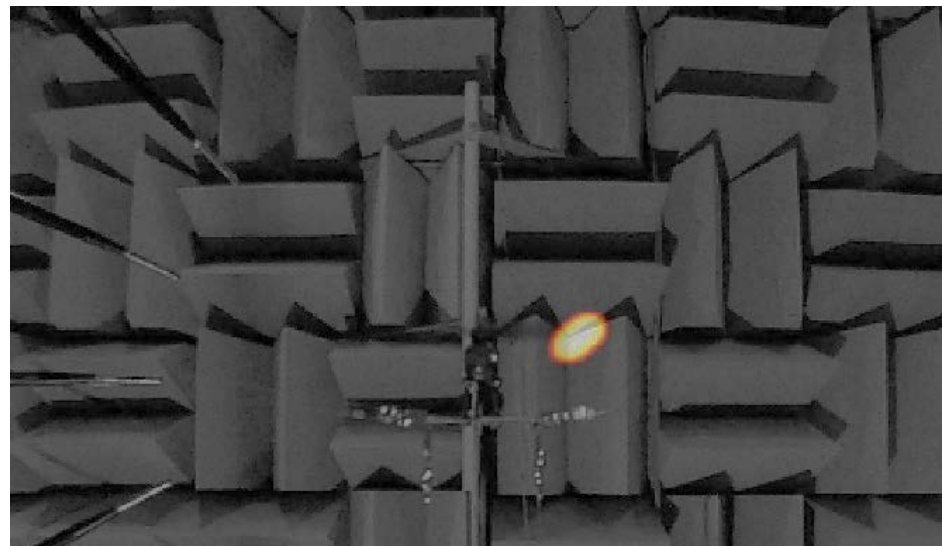
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 5469 Hz



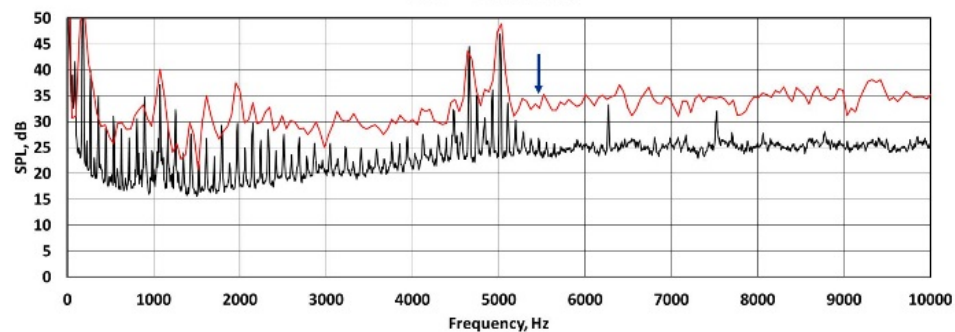
— Mic 7 — Phased Array



Motor Only

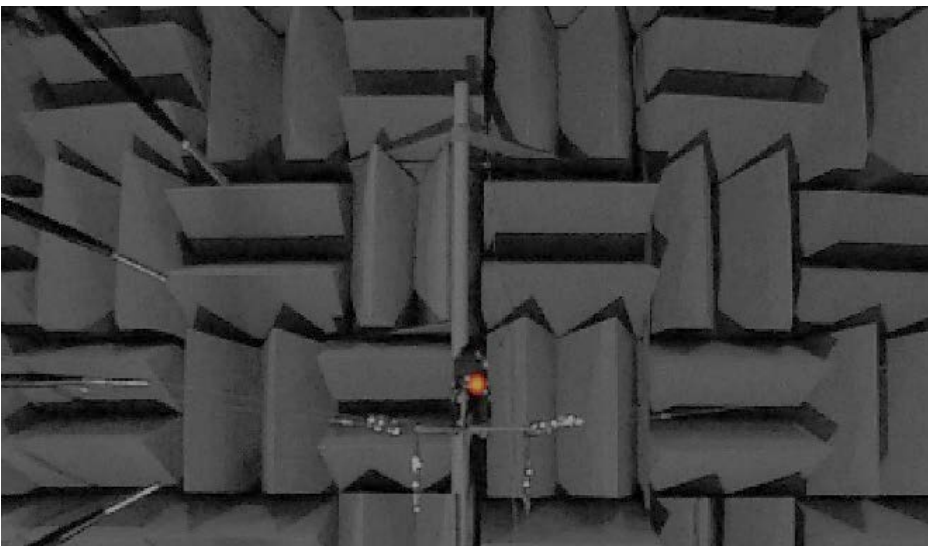


— Mic 7 — Phased Array

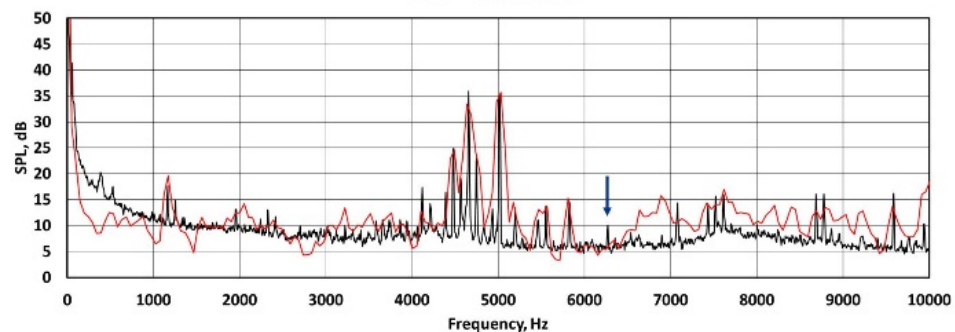


Two-Bladed Propeller

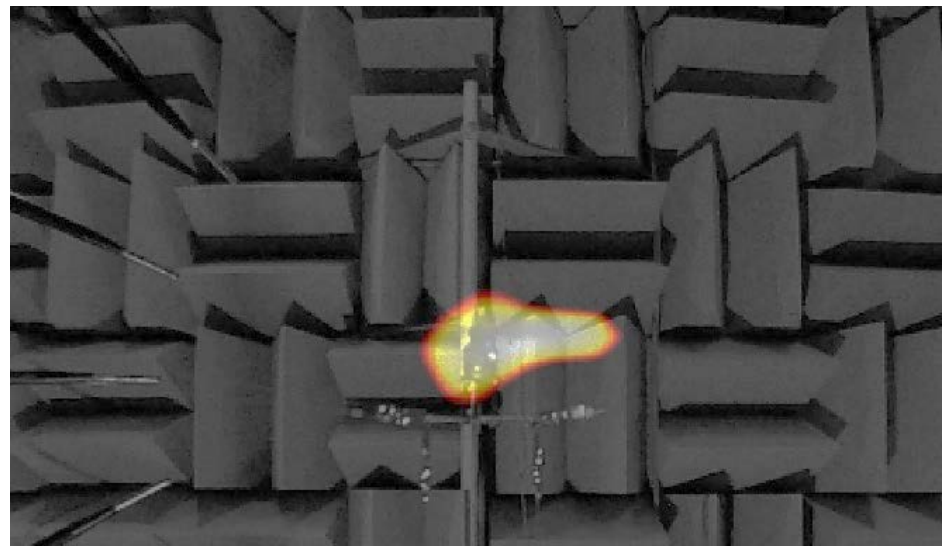
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 6250 Hz



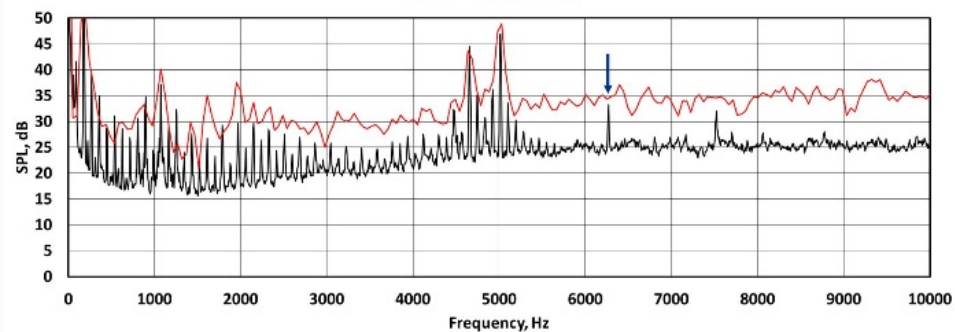
— Mic 7 — Phased Array



Motor Only

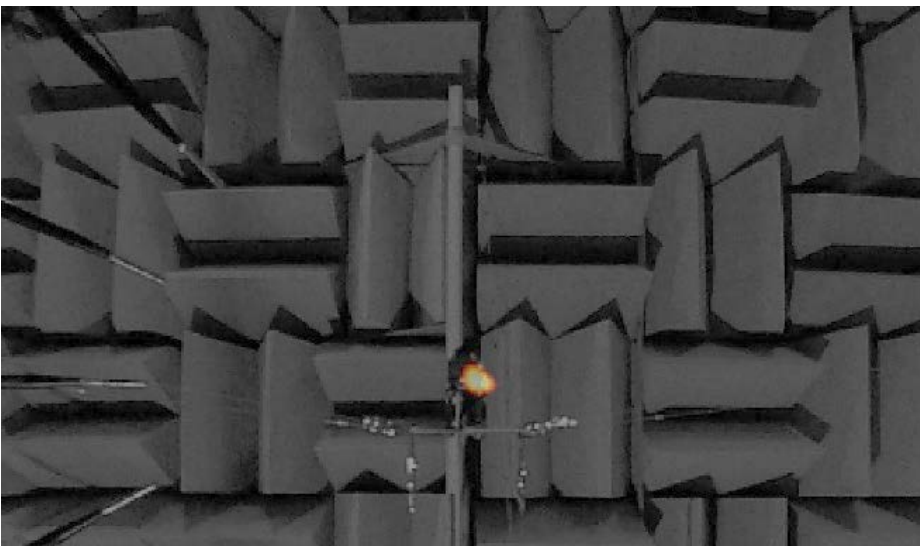


— Mic 7 — Phased Array

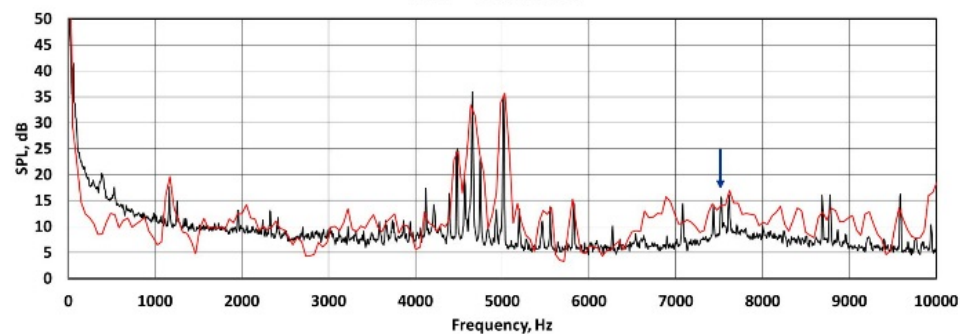


Two-Bladed Propeller

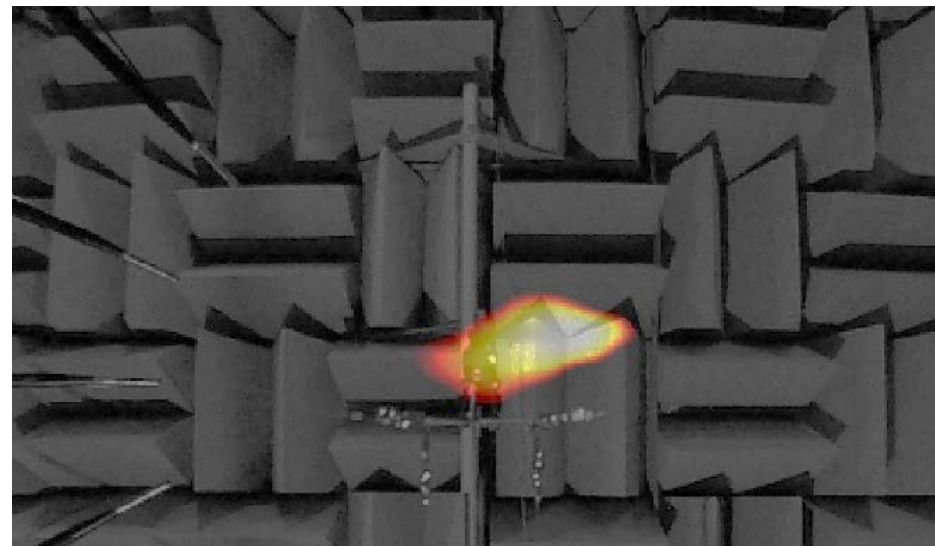
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 7520 Hz



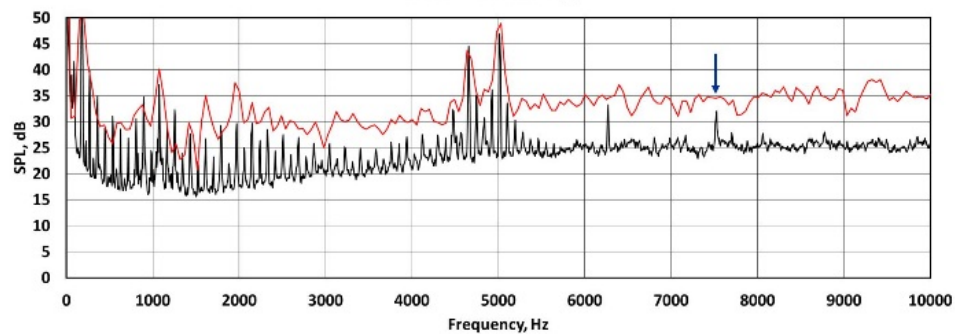
— Mic 7 — Phased Array



Motor Only

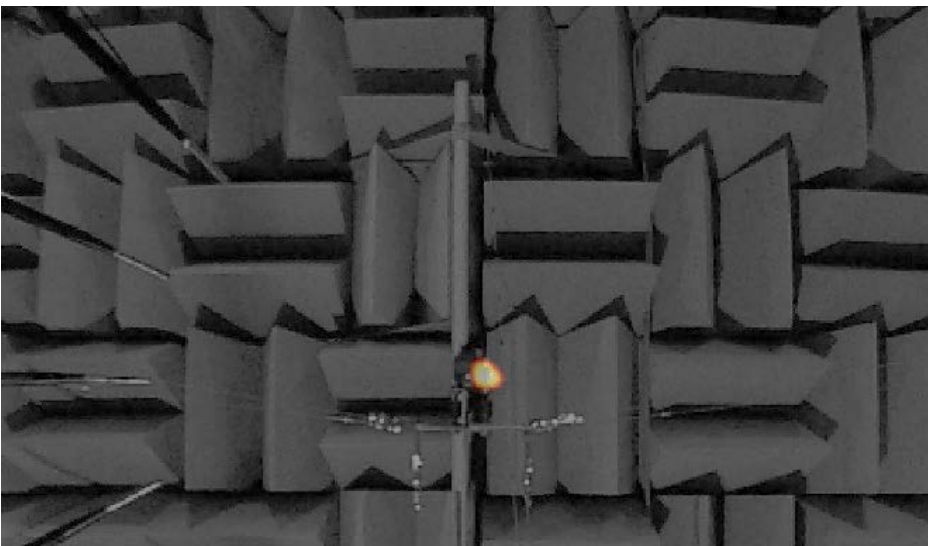


— Mic 7 — Phased Array

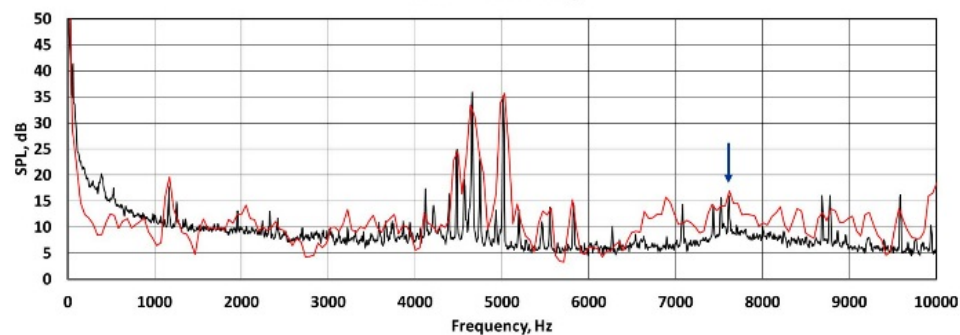


Two-Bladed Propeller

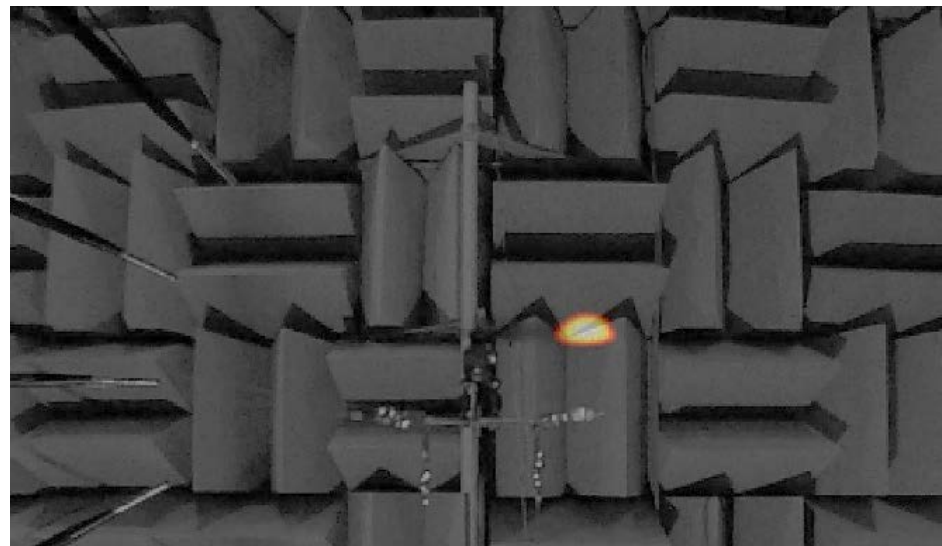
3DR Motor Only vs With Propeller, 5370 RPM Phased Array, 7617 Hz



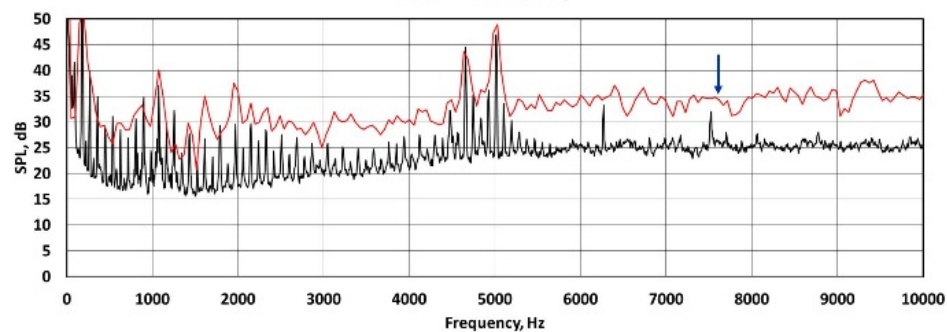
— Mic 7 — Phased Array



Motor Only

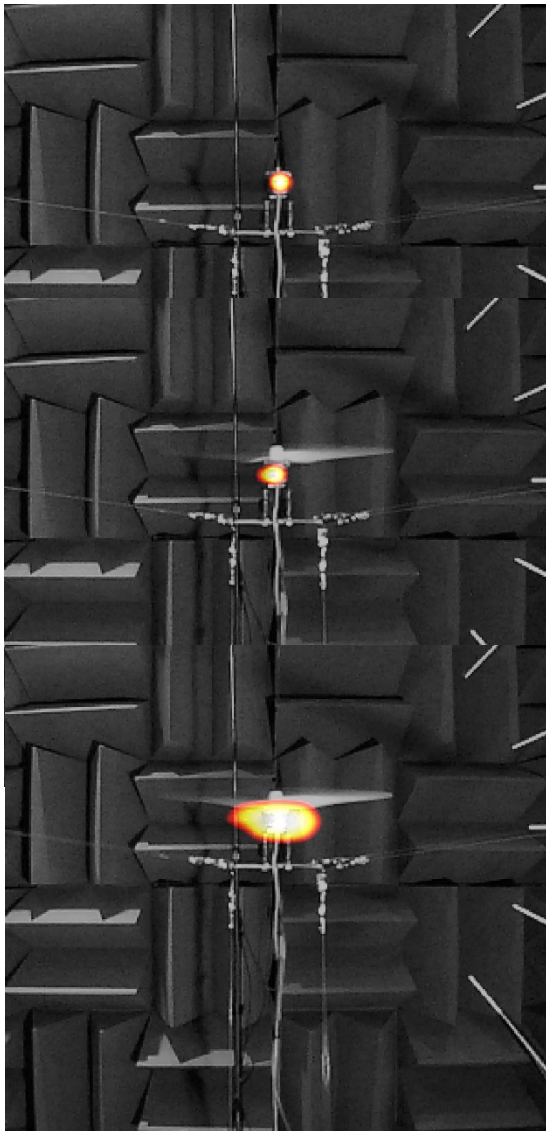


— Mic 7 — Phased Array

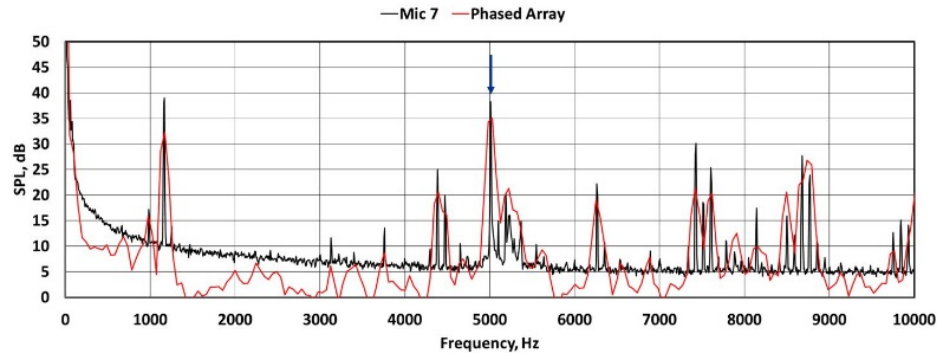


Two-Bladed Propeller

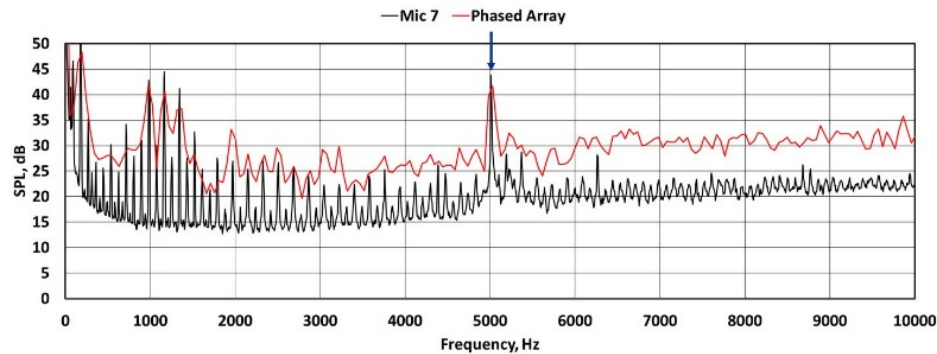
2312 Motor Only vs With Propellers, 5370 RPM Phased Array, 5029 Hz



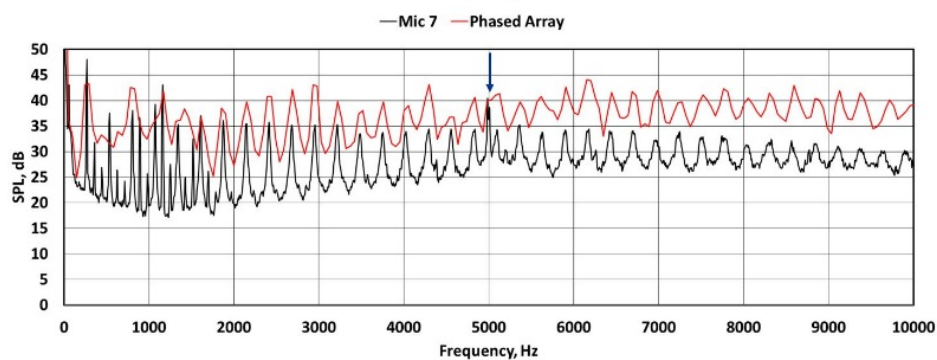
Motor Only



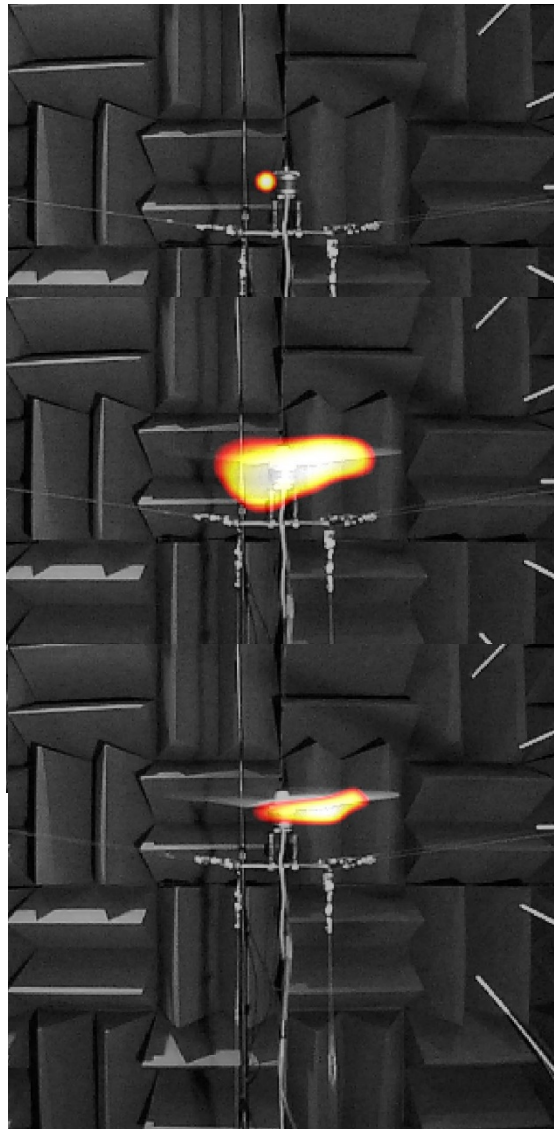
Two-Bladed Propeller



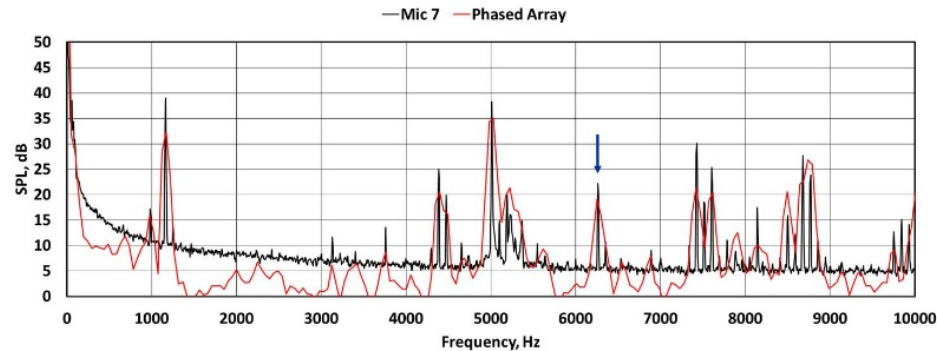
Three-Bladed Propeller



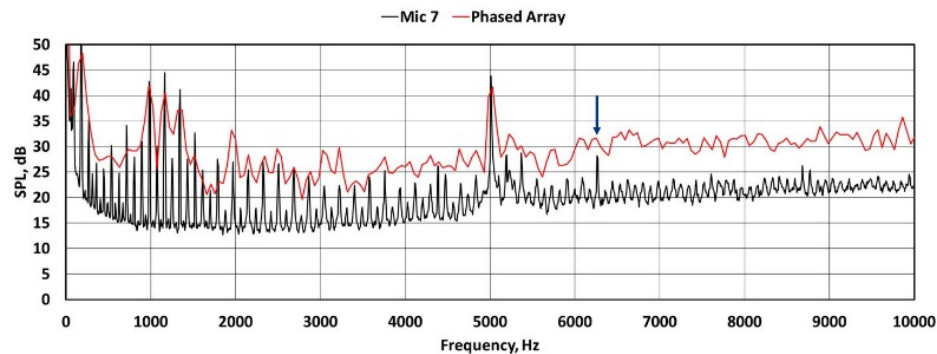
2312 Motor Only vs With Propellers, 5370 RPM Phased Array, 6250 Hz



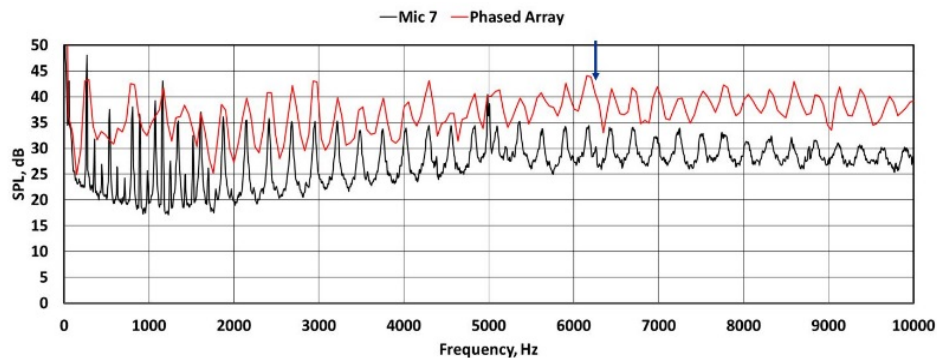
Motor Only



**Two-Bladed
Propeller**



**Three-Bladed
Propeller**





Conclusions

- **Tones are most important noise source.**
- **Motor noise peaks in a direction normal to the motor rotor axis.**
- **Adding a propeller introduces shaft order/blade passing frequency tones, and higher harmonics that are evident up to about 4000 Hz.**
- **Propeller increases the broadband noise across the entire spectra.**
- **Strong motor tones can be amplified by the propeller loading by 5 to 15 dB and can exceed the propeller noise levels.**
- **A phased microphone array provides acoustic spectra that are in good agreement with far field microphone data.**
- **Beamform images successfully distinguish motor and propeller noise contributions.**



This work was supported by NASA's Revolutionary Vertical Lift Technology (RVLT) project in the Advanced Air Vehicles Program.